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# **Magnetohydrodynamics (MHD) Engineering Test Facility (ETF) 200 MWe Power Plant**

## **Design Requirements Document (DRD)**

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**Revision 3  
September 1981**

Prepared for  
**U.S. DEPARTMENT OF ENERGY  
Fossil Energy  
Office of Magnetohydrodynamics**

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Work performed for  
**U.S. DEPARTMENT OF ENERGY**  
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**Office of Magnetohydrodynamics**  
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ENGINEERING TEST FACILITY  
DESIGN REQUIREMENTS DOCUMENT (DRD)  
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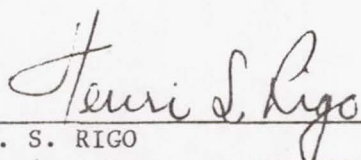
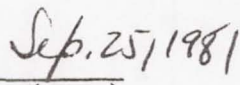
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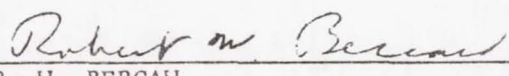
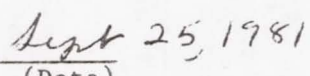


DESIGN REQUIREMENTS DOCUMENT

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## PREFACE

This document presents the design requirements for the preparation of the Conceptual Design of an MHD Engineering Test Facility (ETF) which meet the System Design and Performance Requirements for the Engineering Test Facility, Revision 1 approved 7/24/80, specified by the Office of Magnetohydrodynamics for Fossil Energy, U.S. Department of Energy. This document will be updated and reissued as necessary.

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DOCUMENT REVISIONCHANGE HISTORY

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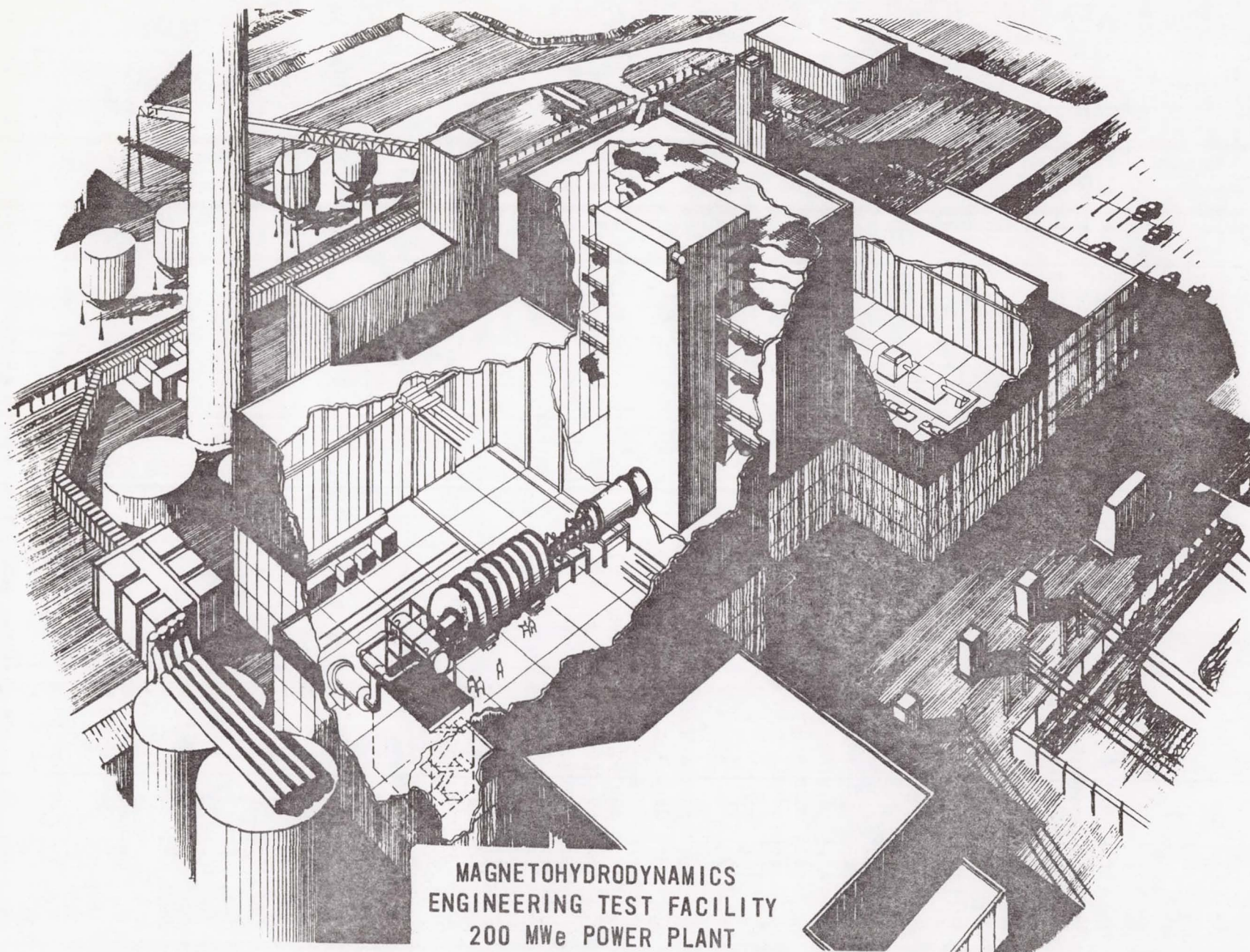
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MAGNETOHYDRODYNAMICS  
ENGINEERING TEST FACILITY  
200 MWe POWER PLANT

VIEW FROM SOUTHEAST, CUTAWAY REVEALING  
MHD TRAIN, HR/SR, AND TURBINE GENERATOR COMPONENTS



GLOSSARY OF TERMS

The following is a list of definitions for technical terms used in the DRD. The definitions are in accordance with the Edison Electric Institute Glossary of Electric Utility Terms and the Bonneville Power Administration (BPA) Glossary.

Ash

The solid residue of the combustion of coal. For MHD combustion the solid residue excludes the compounds formed from the seed.

Availability

Status of equipment which is capable of service whether or not it is in service. The Operating Availability is the percent of time a unit was available for service, whether operated or not. It is equal to the available hours divided by the total hours in the period under consideration, expressed as a percentage.

Average Cost Pricing

In an economic context, the dividing of total cost by the number of units sold in the same period to obtain a unit cost and then applying this unit cost directly as price.

In a public utility context, the pricing of the service without regard to the structure of the market, to recover those portions of total costs associated with each service in order to make total revenues equal total costs.

Auxiliary Equipment

Accessory equipment necessary for the operation of a generating station. This includes pumps, fans, pulverizers, as partial examples.

Auxiliary Power (see Station Power)Base Load

The minimum load on a power system extended over a given period of time, usually a year.

Base Load Operation

Operation at full load or any established load less than 100 percent of full load which is maintained for a long period of time.

Base Load Station

A generating station which is normally operated to provide all or part of the base load of a system, and which operates at nearly constant output.

Capability

The maximum load which a generating unit, generating station, or other electrical unit can carry under specified conditions for a given period of time without exceeding approved design limitations.



Capacity

The load for which a generating unit, generating station, or other electrical apparatus is rated. See Name Plate Rating.

Capacity Factor

The ratio of the average load (kW) on a machine or equipment for the period of time considered (hours) to the rating of the machine or equipment. Also called "plant factor".

Capacity-only Pricing

A system of pricing which includes only a single annual or monthly demand charge with no separate charge for the amount of energy used by the purchaser.

Cleanup (Water Treatment)

A systematic method of cleaning up the condensate, feedwater, cooling and boiler water to meet the manufacturer's and engineer's chemical and physical requirements and criteria. This involves purification by filtration, demineralization, degasification and chemical purification at controlled flow rates, pressures and temperatures.

Conductor

The wire cable supported by transmission towers, through which the electric current flows.

Cooling Tower

A device used with thermal-electric generating plants to dissipate excess heat to the atmosphere. To achieve the cooling effect, air is moved across a large surface wetted with circulating water or through a spray of the circulating water.

Curtailment

Temporary, mandatory load reduction reflecting emergency conditions, following after all possible conservation action and load management techniques have been attempted and prompted by problems of meeting baseload rather than peaking deficiencies.

Dead Band

Resolution sensitivity plus any looseness due to tolerances or lost motion during which control action causes no control effect.

Demand

The rate of electric power required by a system, part of a system, or a piece of equipment expressed in kilowatts, kilovoltamperes or other suitable unit at a given instant or averaged over any designated period of time. The primary source of "Demand" is the power-consuming equipment of the customers.

Demand Factor

The ratio of the maximum demand over a specified time period to the total connected load on any defined system. This shows the simultaneous use made of equipment.

Effluent

A discharge or emission of a liquid or gas, usually waste material.

Emergency Dump (Discharge)

An emergency dump of a superconducting magnet is the action of inserting (by suitable switching or other means) an external electrical resistor across the terminals of the magnet, so that (with power supply shut off) the magnetic energy in the magnet is rapidly removed by being absorbed in the resistor. Simultaneously the electric current and magnetic field are rapidly reduced.

Energy

The cumulative power produced over a stated interval of time; expressed in kilowatthours or megawatthours. Equivalent terms are: energy capability, average generation, firm energy load carrying capability.

Equivalent Pure Oxygen

The term, equivalent pure oxygen, is used in normalizing the output and specific power consumption for air separation units producing pure oxygen. If the air separation unit generates a product that is a mixture of air and oxygen, then equivalent pure oxygen refers only to the pure oxygen component in the product and excludes the oxygen contained in the admixed air.

Exchange Agreement

A contract providing for an exchange, rather than a direct sale, of power, energy, or services.

Facility Location Supplement

A supplementary environmental impact statement issued subsequent to a specific facility planning supplement. It expands upon the facility planning supplement to include alternative locations for a proposed new facility and environmental impacts associated with each alternative location. This supplement is prepared after public and agency review of the final planning supplement has been completed and reconnaissance studies have been made.

Facility Planning Supplement

A supplementary environmental impact statement which identifies the need for a specific new transmission facility proposed as part of the annual construction program and which outlines in preliminary form the probable environmental impact of constructing the facility in accordance with a general proposed system plan and alternative plans.

Forced Outage

An outage that results from emergency conditions caused by having to take a component of the system out of service immediately or as soon as switching operations can be performed.

Forced Outage Rate

Plant availability due to shutdown resulting from component malfunction. This is a ratio of the forced outage hours to the total of hours of operation plus the forced outage hours times 100 percent.



Fossil Fuels

Coal, oil, natural gas and other fuels originating from fossilized geologic deposits and depending on oxidation for release of energy.

Generation Capability

Gross: The generated output power (kW) at the terminals of a generator, as demonstrated by test or as determined by actual operating experience.

Net: Gross generation power (kW) less station power.

Heat Rate

A measure of generating station thermal efficiency, generally expressed in Btu per net kilowatthour. It is computed by dividing the total Btu content of fuel burned for electric generation by the resulting net kilowatt hour generation.

HR/SR

Heat Recovery and Seed Recovery System.

Interconnections

A connection of two or more individual power systems, permitting the transfer of electric energy.

Interruptible Loads (interruptible power)

Loads (power) that can be discontinued in the event of a capacity or energy deficiency on the supplying system.

Kilowatt (kW)

The unit of power which equals 1,000 watts. The electrical and thermal units of power are often abbreviated kWe and kWt respectively.

Kilowatthour (kWh)

A basic unit of electric energy which equals one kilowatt of power applied for one hour.

Load-Frequency Control

The regulation of the power output of electric generators within a prescribed area in response to changes in system frequency, tie-line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits.

MHD-ETF

The Magnetohydrodynamics-Engineering Test Facility is a complete combined cycle electric power generating plant consisting of a MHD topping cycle, Rankine bottoming cycle and all auxiliary equipment, structures, support systems, and utilities.

Megawatt (MW)

The unit of power which equals one million watts or one thousand kilowatts. The electrical and thermal units of power are often abbreviated MWe and MWt respectively.

Megawatthour (MWh)

A basic unit of electric energy which equals one megawatt of power applied for one hour.

Mitigate

In environmental usage, to reduce or control an adverse environmental impact through various measures which seek to make the impact less severe, less obvious, more acceptable, et cetera.

Name Plate Rating (See Capacity)

The full load continuous rating of a generator, prime mover or other electrical equipment under specified conditions as designated by the manufacturer. It is usually indicated on a name plate attached mechanically to the individual machine or device.

Net Dependable Capability Rating

The maximum system load in kilowatt hours (kWh) per hour that a generating unit or station can be depended upon to supply on the basis of average operating conditions.

Nominal

Approximate. Usually used to describe a design parameter or operating condition that is near to but not exactly as given.

Off-Peak

A period of relatively low system demand for electric energy as specified by the supplier, such as occurs in the middle of the night.

OperationNormal Baseload Operation

Operation of the plant at full load or any established load less than full load that is maintained consistently over the complete range of its power generating capability.

Off-Design Operation

Operating condition when a malfunction event causes a component of a vital subsystem to become inoperable, but the system itself continues to operate with redundant components at full or reduced load, without undue operating penalty. Remedial action must be implemented within a period of time during which, statistically, there is low probability of a second malfunction occurring which in combination with the first malfunction would disable the plant. Redundant components are required to support off-design operation and to meet requirements for plant availability and performance with acceptable operating economics.

Full Load

100 percent load continuously at turbine and MHD generator design (nameplate) conditions.



Load Following

The changes in MHD-ETF Plant power setting to respond to changes in electrical demand from the Utility grid.

Low Load

Power below Minimum Load which refers to the transient load profile before the established load is reached. This is a region of unstable and/or unsafe conditions.

Minimum Load

The lowest load which allows stable operation.

Instantaneous Peak Load

The maximum demand at the instant of greatest load, usually determined from the readings of indicating or graphic meters.

Maximum Load

The greatest of all demands of the load under consideration which has occurred during a specified period of time.

No Load

No measurable output produced by any electrical power generation equipment. Steam generation may be measurable and operating temperatures will be less than full load operation. Fuel firing may be in operation. This condition could either precede electric generation or follow immediately after shedding all electric load.

Load Swings

Rate of load change in percent per unit of time. The magnitude of change and the rate are established by the equipment manufacturer.

Load Factor

The ratio of the average load (kW) over a designated period of time to the peak load occurring in that period.

Outage

In a power system, the state of a component (such as a generating unit or transmission line) when it is not available to perform its normal function.

Peaking Capability

The maximum peakload that can be supplied by a generating unit, station, or system in a stated time period. It may be the maximum instantaneous load or the maximum average load over a designated interval of time.

Peaking Capacity

Generating units or stations which are available to assist in meeting that portion of peakload which is above the baseload.

Peakload

The maximum electrical load in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated interval of time.

Peakload Plant

A powerplant which is normally operated to provide power during maximum load periods.

Plant ConditionCold Shutdown (Dead Plant)

All MHD and power generation systems and subsystem shutdown and not operating for an extended period of time.

MHD system, boiler, turbine, fuel system, steam system, water system at ambient temperature and not cleaned.

Hold Condition

A temporary interruption in transient operating procedure or sequence of steps to satisfy the requirements to change from one plant condition to a different plant condition.

Hot Standby

Hot standby is that mode of operation during which certain plant components, which are sensitive to thermal cycling and do not require maintenance at the time, are maintained in a hot condition while the remainder of the plant is shut down to permit inspection and maintenance or component replacement. During hot standby, net power need not be produced.

Warm Standby

Warm standby is the condition of a power plant after a shutdown of typically 48 hours. First stage metal temperature for the steam turbine is between 300°F and 700°F. The steam generator steam output has been reduced to maintain sufficient low pressure steam for turbine warming and sealing, and for maintaining condenser vacuum.

Cold Standby

Cold standby is that condition of a power plant where first stage steam turbine metal temperature is below 300°F. The balance of plant is ready for operation. The auxiliary steam generator is in operation supplying steam for plant uses.

Plant ShutdownTo Hot Standby

Operating sequence during which equipment that is sensitive to thermal cycling is maintained near its operating temperature while less sensitive equipment, e.g., the MHD combustor, is shut down and allowed to cool to temperatures which permit inspection, maintenance, and repair/replacement of equipment.

To Cold Standby

Sequence of events and operational procedures to convert an operating plant to an off the line cold standby condition. A process of transition



from full load to no load in an orderly fashion and in accord with predetermined and programmed steps.

#### To Cold Shutdown

Operating sequence during which all plant systems are shut down, i.e., none are maintained in the hot standby mode, and the plant is removed from service for general inspection and maintenance.

#### Smooth Shutdown

A planned shutdown (to any condition) which follows normal procedures and does not exceed pressure or temperature limitations which degrade the equipment.

#### Emergency Shutdown

Shutdown operation occurring when plant operation is interrupted by casualty events. A casualty event will initiate an emergency shutdown of the plant or system affected.

#### Casualty Event

An abnormal system or plant condition which affects the safety, integrity or proper operation of the system which could produce system or plant degradation or affect personnel safety, and which requires action to restore the plant to a known, confirmed safe condition, or to mitigate the consequence of the casualty event.

### Plant Startup

#### From Cold Shutdown

The plant is brought up to the cold standby mode after the plant has been in the cold shutdown mode. Startup time is that time required to maneuver the MHD and steam cycle operating parameters, e.g., temperature, pressure, mass flow, and loading, from shutdown to normal baseload operating conditions.

#### From Cold Standby

Sequence of events and operational procedures required to bring a plant in the cold standby mode to a normal operating condition.

#### From Warm Standby

Sequence of events and operational procedures required to bring a plant in the warm standby mode to a normal operation condition.

#### From Hot Standby

Operating sequence during which the MHD and steam cycle operating parameters are changed from hot standby to normal baseload operating conditions.

### Power

The time rate of transferring or transforming energy, expressed in watts.

Power Factor

The ratio of real power in kW to the apparent power in kilovolt-amps (kVA).

Quench

A quench in a superconducting magnet is an uncontrolled increase in resistance in part or all of the superconducting winding, such as may happen in the event of loss of coolant or other malfunctions.

Reliability

The ability of a device to perform a required function under stated conditions for a stated period of time. In a power system, the ability of the system to continue operation while either in the design or off design modes.

Reserve Capacity

Extra generating capacity available to meet unanticipated demands for power, or to generate power in the event of loss of generation resulting from scheduled or unscheduled outages of regularly used generating capacity. Reserve capacity provided to meet unscheduled outages is also known as Forced Outage Reserve.

Reserves

A portion of total generating capability planned to be available to serve loads in case of forced outages or unanticipated load growth.

Cold

Thermal generating units available for service but not maintained at operating temperature.

Hot

Thermal generating units available, up to temperature and ready for service, although producing no load.

Spinning

Generating units connected to the bus and ready to take load.

Thermal

The rating of a thermal electric generating unit, or the sum of such ratings for all units in a station or stations.

Resolution Sensitivity

The minimum change in the measured variable which initiates an effective response from the control system.

Scrubbing

Removing pollutants, such as sulfur oxides or particulate matter, from stack gas emissions usually by means of a liquid sorbent.



Secondary Power

Power not having the assured availability of firm power; power that is available from a system intermittently and that is used to serve markets that can accommodate such power.

Seed

A mixture of  $K_2CO_3$  and  $K_2SO_4$  injected into the combustor to provide the electrical conductivity for the plasma produced and to chemically capture the sulfur in the flue gas.

Slag

A combination of ash and seed that has agglomerated into an amorphous mixture.

Slurry

A mixture of a liquid and a solid.

Stack Gas

Gases, usually carbon dioxide, water vapor, nitrogen, and accompanying particulates which result from combustion processes.

Station Power

That portion of the generated power (kW) used by unit or station auxiliaries essential to the operation of the unit or station.

Substation

An electric power station which serves as a control and transfer point on an electrical transmission system. Substations route and control electrical power flow, transform a voltage to a higher or lower voltage, and serve as delivering points to individual customers.

Subsystem

An assembly of components, the integration of which into a system complex provides a specific function needed for system operation.

TBD

To be determined.

Tie Line

A transmission line connecting two or more power systems together, permitting a flow of energy between them.

Transmission Grid

An interconnected system of electric transmission lines and associated equipment for the movement or transfer of electric energy in bulk between points of supply and points of demand.

Unscheduled Shutdown (see Emergency Shutdown)Full Load Trip

Removal of the 100 percent load on the turbine by closing the steam admission valves at their maximum rate.

Turbine Trip

Removal of load on the turbine by closing the steam admission valves at their maximum rate.

Utilization Factor

The ratio of the maximum demand to the rated capacity of any equipment. This shows the maximum use made of equipment.

"Valves Wide Open" (see Capability)

Maximum continuous operational rating of turbine system. Steam admission valves are fully opened.

## Section 1

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## 1.0 Introduction

### 1.1 Scope

This Design Requirement Document describes and provides the design and performance requirements for the Magnetohydrodynamics Engineering Test Facility.

It describes the purpose, general operating conditions, overall lay-out, and principal design characteristics of the ETF. It also defines basic plant requirements relating to performance, durability, reliability, availability, operating range, safety, and environmental effects. Conditions of the process flow streams are presented for major system interface locations.



## Section 2

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## 2.0 General ETF Description

### 2.1 ETF Definition

The Engineering Test Facility will be a commercial prototype, fully integrated MHD topping/steam bottoming power plant, using coal and oxygen enriched air. The facility will be a complete plant rated at 200 MWe and capable of delivering electric power to a utility grid. The facility will operate as a "baseload plant". The facility will also accommodate a wide range of other load changes including load rejection and transients.

The facility will comply with applicable Federal, State, and Local environment regulations at all load levels.

### 2.2 Facility Narrative

The ETF demonstrates the commercial viability of the MHD process for the generation of power from coal. The MHD process directly produces electrical energy by the movement of an electrically conducting fluid through a magnetic field. In a coal-fired MHD power plant, the fluid consists of the gases formed by the combustion of coal.

An MHD generator essentially combines the functions of the steam turbine and electrical generator employed in a conventional system. Because the energy of the gas steam is converted directly to electrical energy, an MHD generator is, in principle, a much simpler device than the conventional turbogenerator. It has neither the highly-stressed moving parts of a turbogenerator, nor any solid parts that are not readily accessible for external cooling; thus, it can withstand temperatures well beyond the capabilities of conventional turbines. As a consequence of high-temperature operation, power plants incorporating MHD generators are potentially more efficient than conventional turbine power plants.

The MHD Power Train consists of the MHD generator (channel and diffuser), a coal combustor and nozzle, and an inverter. A superconducting magnet surrounding the channel provides the magnetic field needed for power generation. Coal is burned in the combustor with the pressurized oxidant to produce a high temperature gas. This gas is ionized by the addition of "seed" composed of a mixture of potassium salts. It is then accelerated by a nozzle to near sonic velocity and discharged into the MHD channel where both thermal and potential energy are used to generate dc electrical power by the magnetohydrodynamic process. The power is collected by a set of electrodes in the channel wall, consolidated, and then inverted from dc to ac for transmission to the distribution network. A diffuser improves the performance of the generator by converting the kinetic energy of the high velocity gas leaving the channel into static pressure.

Coal, seed and oxidant are supplied to the MHD power train combustor by independent systems. To provide the combustion temperature which is adequate to ionize the seed, oxidant is prepared by mixing air with

## Section 2

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## 2.0 General ETF Description

### 2.1 ETF Definition

The Engineering Test Facility will be a commercial prototype, fully integrated MHD topping/steam bottoming power plant, using coal and oxygen enriched air. The facility will be a complete plant rated at 200 MWe and capable of delivering electric power to a utility grid. The facility will operate as a "baseload plant". The facility will also accommodate a wide range of other load changes including load rejection and transients.

The facility will comply with applicable Federal, State, and Local environment regulations at all load levels.

### 2.2 Facility Narrative

The ETF demonstrates the commercial viability of the MHD process for the generation of power from coal. The MHD process directly produces electrical energy by the movement of an electrically conducting fluid through a magnetic field. In a coal-fired MHD power plant, the fluid consists of the gases formed by the combustion of coal.

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The MHD Power Train consists of the MHD generator (channel and diffuser), a coal combustor and nozzle, and an inverter. A superconducting magnet surrounding the channel provides the magnetic field needed for power generation. Coal is burned in the combustor with the pressurized oxidant to produce a high temperature gas. This gas is ionized by the addition of "seed" composed of a mixture of potassium salts. It is then accelerated by a nozzle to near sonic velocity and discharged into the MHD channel where both thermal and potential energy are used to generate dc electrical power by the magnetohydrodynamic process. The power is collected by a set of electrodes in the channel wall, consolidated, and then inverted from dc to ac for transmission to the distribution network. A diffuser improves the performance of the generator by converting the kinetic energy of the high velocity gas leaving the channel into static pressure.

Coal, seed and oxidant are supplied to the MHD power train combustor by independent systems. To provide the combustion temperature which is adequate to ionize the seed, oxidant is prepared by mixing air with

oxygen from an on-site Air Separation Unit (ASU). The blended oxidant is then compressed and heated to an intermediate temperature.

Considerable energy is contained in the MHD exhaust gas. The ETF utilizes most of it to generate steam which is used to drive a turbogenerator, providing additional electrical power, and drive the air and oxidant compressors and other auxiliary equipment.

The ETF uses nonconventional processes to control emissions of sulfur and the  $\text{NO}_x$  formed during combustion. The sulfur combines preferentially with the potassium seed to form particulates which are removed from combustion gases by conventional methods. Recovered seed can be reused once it has been reprocessed to remove the sulfur, but reprocessing facilities are not included in the ETF.  $\text{NO}_x$  emissions are limited by sub-stoichiometric (fuel rich) combustion followed by a time controlled temperature reduction of the exhaust gases that allows the  $\text{NO}_x$  to reduce to a low concentration.

### 2.3 Identification of Plant Systems

The ETF is organized into a number of systems, each performing one or more specific functions. Related systems are grouped together in separate sections of the DRD. These sections are:

- Oxidant Supply
- MHD Power Train
- Magnet
- Heat Recovery/Seed Recovery
- Steam Power Train
- Plant Auxiliaries
- Plant Services

The functions and design requirements of the Oxidant Supply, MHD Power Train, Magnet, Heat Recovery/Seed Recovery, Steam Power Train, Plant Auxiliaries and Plant Service systems, are presented in Sections 5 through 11. These sections expand the detail of performance requirements presented in Section 3. The arrangement of these systems, except for plant auxiliaries and services, are illustrated in Figure 2.1.

### 2.4 Buildings

The plant includes structures and buildings normally associated with a coal-fired generating plant. Also included are the structures for an air separation unit, a building to house the magnet and MHD power train, and related ancillary structures needed to complete the facility. The character and appearance of the plant will be similar to conventional fossil power plants.



## 2.5 Site Conditions

The ambient design conditions for the ETF are listed in Table 2.1.

TABLE 2.1  
AMBIENT DESIGN CONDITIONS

	Dry Bulb Temperature °F	Wet Bulb Temperature °F	Pressure psia
Plant Design Point	42	36	13.0
Summer Design Point	80	59	13.0
Winter Design Point	-7	-8	13.0

These conditions are typical of sites located in Montana. The region is characterized by plains, widely dissected by streams and having strong local relief of 5-50 ft.

The hypothetical site is relatively large and flat and located 10 miles from the nearest town. Relatively flat areas of up to 1000 acres are available.

The hypothetical site location contains a transportation system, composed of railroads, an airport, and federal and state highways. Access to the site will be provided by constructing an access road which connects to a major highway. Railroad access will be provided by constructing a spur line to a major railroad line, within 5 miles of the site location. All plant shipments for both construction and operation, including fuel delivery, are assumed to be overland.

Power for construction will be available at the hypothetical site from the local electric utility. Water for construction and operation activities will be obtained from a surface source within 1 mile of the site location.

In the vicinity of the hypothetical site, calm wind periods account for nearly one third of the observation during the morning and early afternoon, and for one fourth of all observations. The remainder of the time, the wind blows from all sectors with a similar frequency of occurrence. Average wind speeds are 20 mi/hr during unstable conditions and 4 mi/hr during stable conditions. On an annual basis, wind blows generally in the southeast direction.

The design meteorology history for the hypothetical ETF site is listed in Table 2.2 is at an altitude of 3300 ft above sea level.

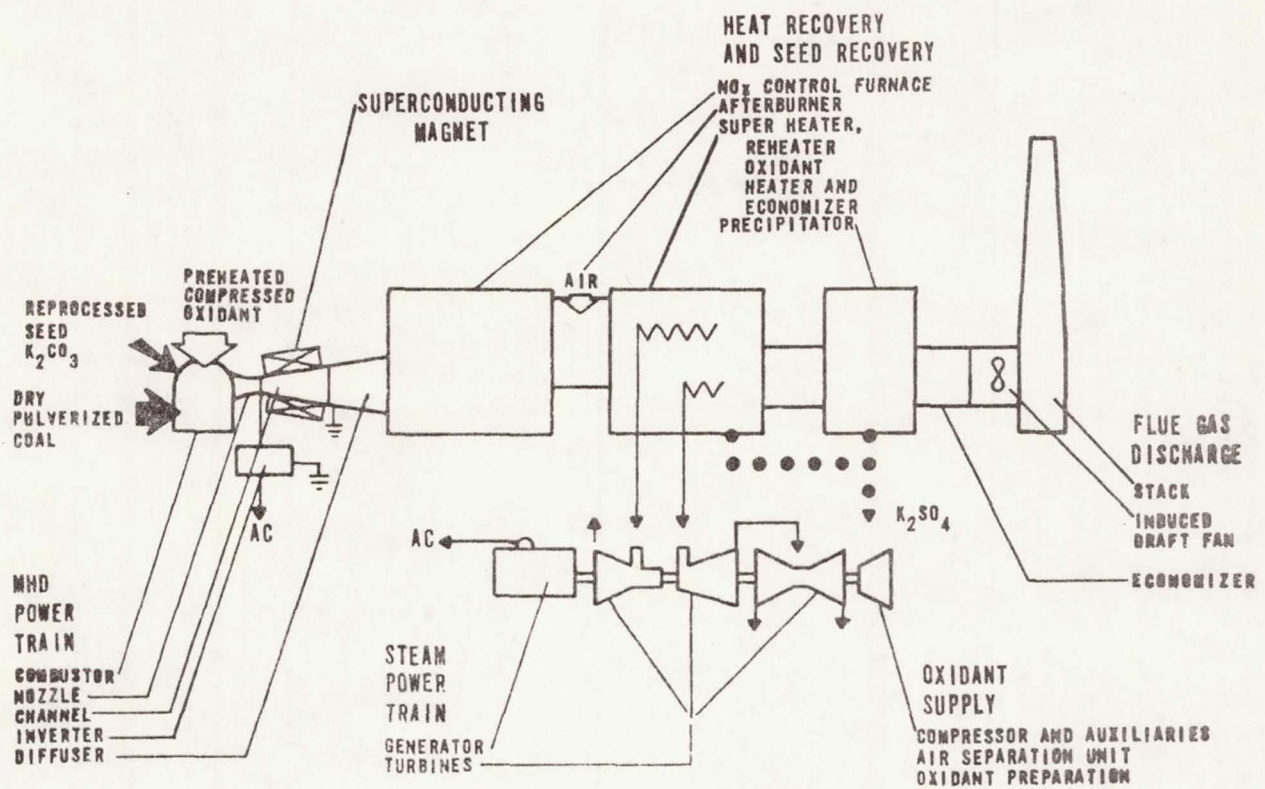


The hypothetical site is located in seismic zone 2 and contains alluvial fill to depths of 500 ft or more. The fill rests on an irregular bedrock surface of moderate relief. This alluvia is a poorly sorted mixture, ranging from fine silty clay to boulders and conglomerates. The alluvial fill at the site is highly permeable. The site presents no serious problems either for site preparation by grading or for construction of facilities.

TABLE 2.2  
WEATHER DATA (HYPOTHETICAL SITE)

<u>Dry Bulb Range °F</u>	<u>Hrs/Year</u>	<u>Mean Wet Bulb °F</u>
100-104	1	63
95-99	10	62
90-94	57	61
85-89	132	60
80-84	202	59
75-79	282	57
70-74	393	55
65-69	484	53
60-64	617	50
55-59	730	47
50-54	839	44
45-49	855	40
40-44	857	36
35-39	787	32
30-34	679	29
25-29	476	25
20-24	349	21
15-19	216	16
10-14	181	11
5-9	159	6
0-4	151	2
-5 to -1	119	-3
-10 to -6	91	-8
-15 to -11	57	-13
-20 to -16	23	-18
-25 to -21	14	-23
-30 to -26	4	-28
-35 to -31	1	-32

FIGURE 2.1  
COAL-FIRED MHD TOPPED STEAM POWER PLANT





## Section 3

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### 3.0 Design Performance and Requirements

#### 3.1 Plant Type

The ETF will operate as a baseload plant.

#### 3.2 Plant Rating

Power	200	MWe Net (Reference)
Voltage	TBD	kV ( $\pm$ TBD kV to be compatible with utility grid)
Frequency	60	Hz -1% to 0%, three phase
Duration	TBD	hrs continuous operation at rated conditions

#### 3.3 Plant Fuel

The plant will be designed to burn coal from the Montana Rosebud (MR) seam.

As received coal properties include:

H <sub>2</sub> O	27% maximum
Ash	12% maximum
Sulfur	1.1% maximum
HHV	11,500 Btu/lb, typical dry

#### 3.4 Load Range

The ETF plant shall be capable of continuous operation over a range of from 75% to 100% of the (reference) plant rating.

#### 3.5 Plant Regulation and Response

Regulation range:

75% to 100% of (reference) plant rating.

Load following:

The power plant will be capable of reducing power output from rated load to 75 percent of rated load and of increasing the power output from 75 percent of rated load to rated load at rates of at least 3 MW per minute.

Frequency Control:

When the ETF is connected to the grid system and the grid frequency deviates by more than  $\pm$  five (5) percent from 60 Hz the ETF shall be separated from the grid for unit protection. If duration of operation below 57.5 Hz is indeterminate or if frequency falls below 57 Hz, this condition shall be cause for tripping the unit.

A deviation greater than 0.06 percent of frequency (equal to deadband) shall be cause for a restoring response in stable fashion within 0.2 seconds.

Design operation at steady state shall be based on frequency changes not in excess of +0.02 Hz, -0.04 Hz exclusive of deadband. Deadband shall not exceed 0.036 Hz.

#### Stability:

The MHD/steam generating unit shall be designed to be inherently stable under all combinations of manual and automatic control while connected to the grid system.

#### Load Regulation:

The power plant will be capable of accommodating load changes about steady state power levels at rates of at least 3 MW per minute.

#### 3.6 Plant Efficiency

	100% Rating (REF)	75% Rating
Net overall (minimum)	37%	TBD
MHD topping cycle (minimum)	TBD	TBD
Steam bottoming (minimum)	TBD	TBD

#### 3.7 Lifetime

The ETF shall be designed and constructed in accordance with utility practice for a thirty year life. The number of operating cycles to be assumed for design calculation purposes is TBD.

#### 3.8 Availability/Reliability

The overall plant shall have at least a 75% availability level when operating under commercial power generation conditions.

#### 3.9 Operational Modes

The ETF will be expected to operate as a baseload power plant. However, the ability to handle multiple startups and shutdowns annually will be a strong factor in selection and design of power equipment.



### 3.9.1 Cold Startup

Typical startup sequences will include but not be limited to:

- Cold Flush
- Hot Cleanup (Waterside)
- Combustor Light-off
- Boiler Start
- Turbine Start
- Turbine - Generator Synchronization
- Turbine - Generator Load
- MHD Generator Start
- MHD Generator Load

### 3.9.2 Baseload

Baseload is operation of the plant at full load or any established load less than full load that is maintained consistently over the complete range of its power generating capability.

### 3.9.3 Standby

Standby is a no-load condition of the power generating equipment. Components that will not be serviced during standby will be maintained in as warm a condition as appropriate for an anticipated restart of the plant. These components are kept ready for operation. Components to be serviced will be allowed to cool for handling by plant personnel. Two basic modes of standby are the hot and cold condition. Typical hot standby conditions are:

- Major components (turbine, boiler, etc.) temperatures are held as warm as possible to reduce thermal warming time to operating conditions.

- Main turbine is on turning gear with sealing steam supplied from auxiliary steam system.

- Condenser vacuum is maintained, circulating water pump(s) operating.

- System water cleanup continues.

- Startup air heaters operating.

- Air and gas flows minimum.

- Fuel and oxidant systems ready to operate.

All auxiliaries ready or operating.

Typical cold standby conditions are:

Equipment is allowed to cool but is still ready for operation.

First stage steam turbine metal temperature is below 300°F.

System water cleanup may be operating.

Cooling water system and other auxiliary systems operating or ready to operate.

Cold startup may be initiated at any time.

#### 3.9.4 Shutdown

Shutdown is a transient mode of operation from normal baseload condition to standby or dead plant. During shutdown appropriate procedures will be followed to bring the plant to the required standby mode or dead plant condition. Equipment limitations will not be exceeded during shutdown which would produce degradation to the component operating characteristics. Typical shutdown sequence will include but not be limited to:

Reduction of load uniformly between MHD and steam turbine generators.

Control of cooling water, gas, and air flow reduction to prevent thermal stress conditions.

Conversion to air oxidant.

Reduction and cessation of fuel flow.

Startup and shutdown of oil burners (vitiating heaters).

Turbine trip, coast down, and placed on turning gear.

Shutdown of support systems and auxiliaries as no longer required.

#### 3.9.5 Emergency Shutdown Mode

(TBD)

#### 3.9.6 Breach of Security

(TBD)



### 3.9.7 Miscellaneous Events

Any event for which procedures have not been prepared and which (in the opinion of responsible plant operators) creates a menace to personnel or major equipment shall justify initiation of shutdown.

### 3.9.8 Testing

All systems and subsystems shall be tested to assure compliance with plans and specifications in a manner consistent with the usual acceptance requirements for this type of equipment. In addition the specialized testing of the following MHD hardware is TBD:

- MHD Power Train
- Magnet
- Heat Recovery and Seed Recovery

### 3.10 Environmental

The ETF shall comply with Federal, state and local air, water and solid waste management standards.

### 3.11 Safety and Health

The ETF shall comply with the following safety standards:

Occupational Safety and Health Standards, Department of Labor, 29 CFR 1910.

Interim Standards for Occupational Exposure to Magnetic Fields, Memorandum, 7/23/79, E. Alpen, Lawrence Berkely Laboratory to K. Baker, Division of Safety, Standards and Compliance, U.S. Energy Research and Development Administration.

### 3.12 Design Codes and Standards

The design shall be in accordance with nationally recognized codes and standards. Specific state and local site codes shall apply. Specific codes listed in the subsequent parts of this document are representative of codes to be utilized in the design. The listings should not be construed as complete.

### 3.13 Performance Assurance

A plan shall be developed for the preparation of an ETF Performance Assurance Program. The program shall detail actions and responsibilities to be used to provide confidence of satisfactory in-service performance. The basic concept of the program shall be that features most important to satisfactory performance be clearly identified and receive specific attention. Identification of important features shall be based on safety and reliability assessments of the probability of failure and the consequences of failure.



### 3.14 Quality Control

Appropriate actions shall be taken during design and construction to assure that the level of quality of the design, manufacture and installation of all systems, equipment and structures is in accordance with the quality control requirements of the Performance Assurance Plan.

## Section 4

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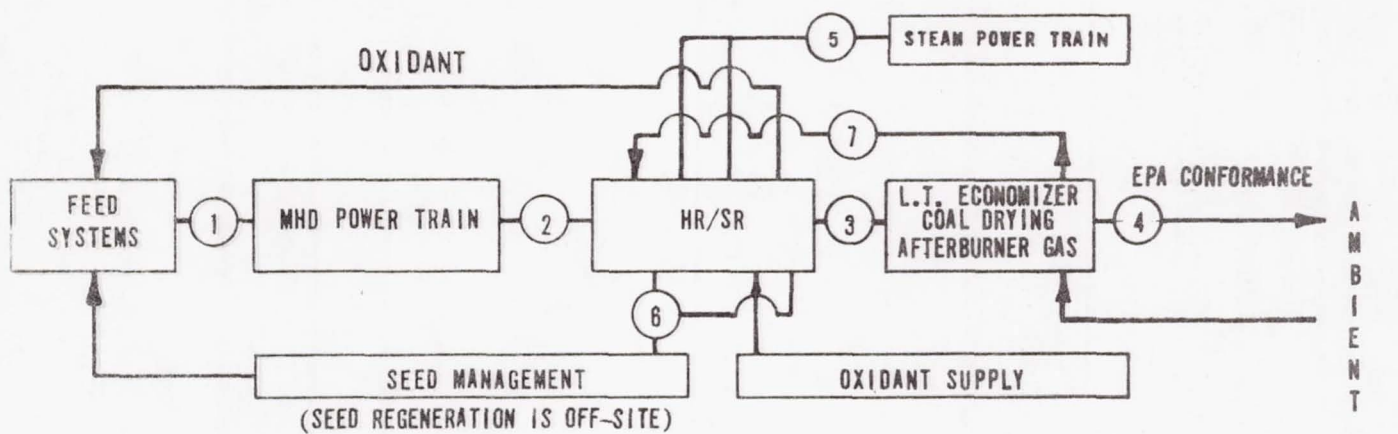
#### 4.0 Major System Interfaces

Because of the close integration of the topping and bottoming cycles in the ETF, the establishment of the design parameters for any one of the major systems biases or restricts the establishment of the parameters of the others. Therefore, the parameters have been set through system calculations which maximize the overall plant efficiency under conditions which minimize such cost drivers as compressor power, magnet length and oxygen enrichment factor. In this process, selected parameters have been constrained to values representing the best estimates of available technology. These additional design requirements include such parameters as materials limited temperatures, electrical limitations on the MHD channel, times and temperatures required for the completion of critical chemical reactions, et cetera.

The location of interface stations between major ETF systems in the process gas flow is presented in Figure 4.0. The process conditions at each of these stations are presented in Table 4.0. Values are computed from thermodynamic heat and mass balances except where they are noted as design requirements (DR). The location of interface stations within the Steam Power Train is presented in Figure 4.1. The process conditions at each of these stations are presented in Table 4.1.



FIGURE 4.0  
MAJOR ETF SYSTEM INTERFACE STATIONS  
(PROCESS GAS FLOW)



- |                   |                          |                     |
|-------------------|--------------------------|---------------------|
| ① COMBUSTOR INLET | ④ FLUE GAS EXHAUST INLET | ⑦ AFTERBURNER INLET |
| ② DIFFUSER OUTLET | ⑤ STEAM INLET            |                     |
| ③ HR/SR OUTLET    | ⑥ SEED RECOVERY INLET    |                     |

# PROCESS CONDITIONS AT SYSTEMS INTERFACE

TABLE 4.0

STATION (FIG 4.0)	FORM	CONDITION	REFERENCE	REMARKS
①	Coal	Ash, % Sulfur, % Flow, lb/hr HHV, Btu/lb H <sub>2</sub> O, %	10.7 1.04 165,622 10,962 5	12=max, DR, See Section 3.3 1.1 = max, DR, See Section 3.3  DR, See Section 3.3 DR, See Section 10.1
	Oxidant	Temperature, °F Pressure, psia Oxygen, % by volume Flow, lb/hr	1,100 70 30 867,852	DR, See Section 8.0  DR, See Section 5.0
	Seed	Potassium mass flow/seeded combustion gas flow Potassium/sulfur mol ratio Potassium mass flow, lb/hr	0.01 1.1 (10,486) 10,511	DR, See Section 10.2 Bracketed numbers are for initial cycle
②	Combustion Gases Plus Seed Products	Temperature, °F Pressure, psia Velocity, ft/sec Flow, lb/hr Stoichiometry	3,532 13.0 300 1,048,569 0.9	DR, See Section 8.0
	Ash Products	Flow, lb/hr	2,173	

DR: Design Requirement

## PROCESS CONDITIONS AT SYSTEMS INTERFACE

TABLE 4.0 CONTINUED

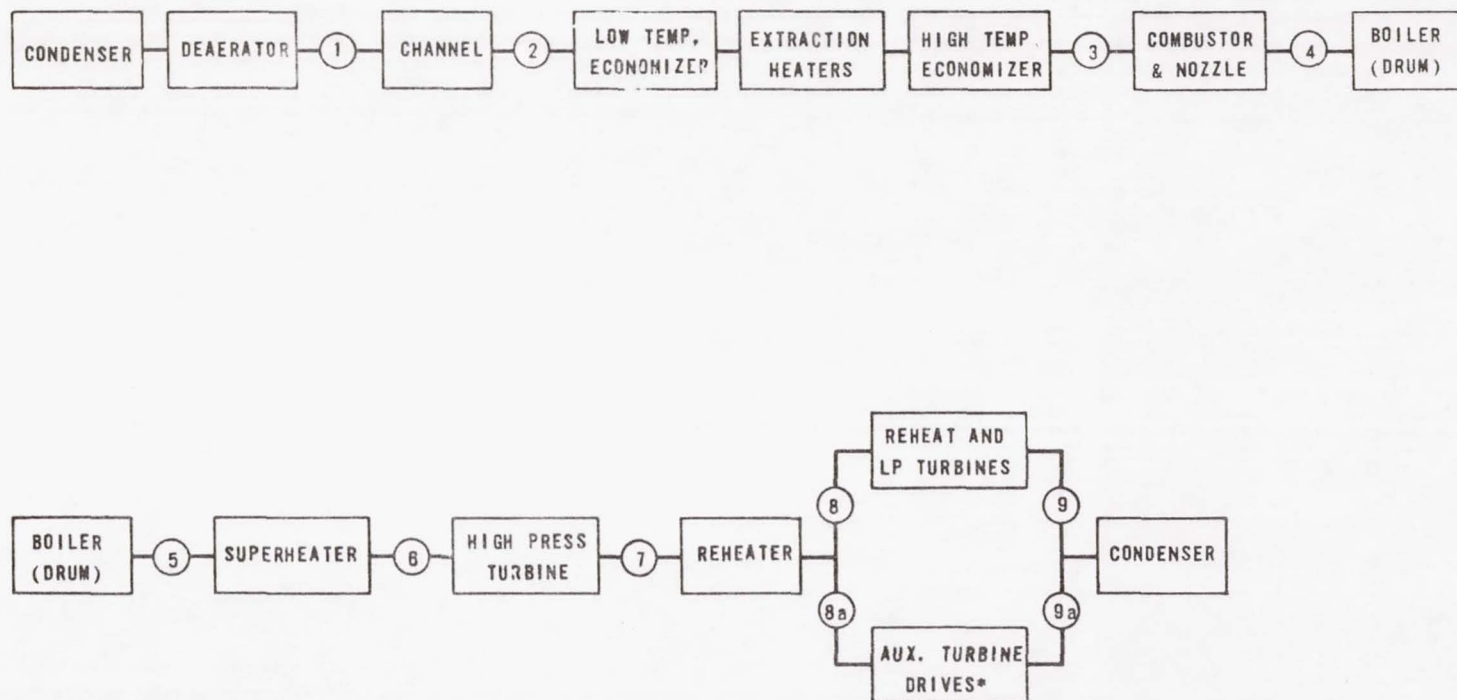
STATION (FIG 4.0)	FORM	CONDITION	REFERENCE	REMARKS
③	Combustion Products	Temperature, °F Pressure, psia Velocity, ft/sec Flow, lb/hr Stoichiometry	480 12.75 3.5 1,357,354 1.05	DR, See Section 8.1  DR, See Section 8.1
④	Combustion Gas	Temperature, °F Pressure, psia Velocity, ft/sec Flow, lb/hr	221 12.57 50 1,258,874	@I.D. fan inlet DR, See Section 2.5



PROCESS CONDITIONS AT SYSTEMS INTERFACE

TABLE 4.0 CONTINUED

STATION (FIG 4.0)	FORM	CONDITION	REFERENCE	REMARKS
⑤	Steam	Superheat temperature, °F Superheat pressure, psia Superheat flow, lb/hr Reheat temperature, °F Reheat pressure, psia Reheat flow, lb/hr	1,005 1,910 1,070,992 1,001 429 986,470	DR, See Section 9.0 DR, See Section 9.0  DR, See Section 9.0
⑥	Seed Recovery Inlet Conditions	Potassium/sulfur ratio Mass flow, lb/hr	2.5 (10,355) 10,478	Ash is principal impurity in seed Bracketed numbers are for initial cycle.
⑦	Afterburner Air	Temperature, °F Pressure, psia Flow, lb/hr	375 12.95 310,957	Incl 8% recycle flue gas



\* DRIVES FOR:

OXIDANT COMPRESSORS  
ASU COMPRESSOR  
BOILER FEED PUMPS

FIGURE 4.1  
STEAM POWER TRAIN INTERFACE STATIONS

TABLE 4.1

PROCESS CONDITIONS WITHIN THE STEAM POWER TRAIN

Station (Fig. 4.1)	1	2	3	4	5
Flow, lb/hr	1,070,992	1,070,992	1,070,992	1,070,992	1,070,992
Pressure, psia	250*	250*	2269**	2269**	TBD
Temperature, °F	214	286	530	TBD	TBD

Station (Fig. 4.1)	6	7	8	8a	9	9a
Flow, lb/hr	1,070,992	986,470	675,917	310,553	536,712	310,553
Pressure, psia	1910	451	429	429	1.23	1.23
Temperature, °F	1005	649	1001	1001	101	101

\* delivery pressure of booster pump

\*\* delivery pressure of boiler feed pump



## Section 5

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## 5.0 Oxidant Supply

This system provides pressurized oxidant to the intermediate temperature oxidant heater section of the HR/SR at the flow rate and pressure required for the operation of the MHD Power Train. The oxidant is prepared by blending atmospheric air with oxygen from the air separation unit. The mixture is then compressed.

Major elements of the system are:

- Air separation unit (ASU)
- ASU compressor and auxiliaries
- Oxidant preparation subsystem

Major interfaces are:

- Steam power train
- HR/SR
- Electrical power system
- Circulating water system

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Oxygen enrichment	See Section 4, Table 4.0
Delivery pressure	See Section 4, Table 4.0
Delivery temperature	430°F
Flow rate	See Section 4, Table 4.0
Internal parameters	System shall be optimized for minimum power consumption and capital costs. Values specified in subsystem sections result from preliminary studies.

### 5.1 Air Separation Unit (ASU)

The ASU produces a medium purity oxygen stream by separating air into its oxygen and nitrogen components in a cryogenic double distillation column. The oxygen product is delivered as a gas at near ambient conditions. Some liquid oxygen and nitrogen product may be withdrawn for storage for plant startup and auxiliary uses.

Major elements of the ASU include:

- Reversing heat exchanger and reversing valves
- Lower and upper distillation columns
- Expansion turbines and valves
- Impurity absorbers

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Specific power consumption (from ASU Compressor drive)	221 kW-hr per ton of equivalent pure oxygen (maximum specific power)
Product oxygen pressure	13.5 psia
Product oxygen purity	70% by volume
Capacity	1550 tons per day of contained oxygen

### 5.2 ASU Compressor and Auxiliaries

This system provides compressed air to the ASU at near ambient temperature.

Major elements include:

Filter and silencer  
Compressor and steam turbine drive  
Intercooler(s)  
Aftercooler

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Delivery pressure	57 psia
Compressor type	Intercooled, aftercooled
Capacity	566,000 lb/hr
Power	12,300 kW maximum

### 5.3 Oxidant Preparation

The Oxidant Preparation System blends incoming atmospheric air with oxygen product from the ASU in a mixing chamber to provide an oxygen enriched stream suitable for operation of the MHD Power Train. The blended oxygen stream is compressed by an uncooled axial compressor rated for 40 mole percent oxygen enriched air service. The blended stream is delivered to the HR/SR for heating and delivery to the MHD combustor.

Liquid oxygen storage is provided for startup and to improve plant availability. Liquid nitrogen storage is provided for magnet cryogenic and plant auxiliary uses.



## Major elements include:

Oxidant compressors and steam turbine drives  
Filter and silencer  
Mixing chamber  
Liquid oxygen and liquid nitrogen storage tanks  
Evaporators

## System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Delivery conditions	See Section 5.0 requirements
Oxidant compressor power (at 100% flow)	23,600 kW maximum

## Section 6

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## 6.0 MHD Power Train System

The MHD Power Train System generates ac electric power from the combustion of coal using the magnetohydrodynamics process. It is the major portion of the ETF topping cycle and is an integrated system consisting of:

Combustion Subsystem (combustor, nozzle and slag removal equipment)

MHD Generator Subsystem (channel, consolidation circuitry and diffuser)

Inverter Subsystem

Control Subsystem

Direct current (dc) electric power is generated in the MHD channel through the interaction of high velocity plasma with a magnetic field. The electric current is collected by electrodes in the channel walls and combined into a few current sources by consolidation circuitry. The currents from these dc sources are then inverted to alternating current for transmission by the Utility grid.

The plasma required for power production is produced by combusting pulverized coal with a pressurized oxidant and adding potassium seed to achieve adequate electrical conductivity. The high temperature needed to ionize the seed is obtained by enriching the combustion air with oxygen and preheating it to a temperature consistent with the state-of-the-art of metallic recuperators. Some excess coal is used in the combustion to limit the production of oxides of nitrogen ( $\text{NO}_x$ ) by the high temperature and to provide the necessary reducing condition in the Heat and Seed Recovery System (HR/SR) for the elimination of the  $\text{NO}_x$  prior to its release from the exhaust gas to the atmosphere.

Coal ash, released in the combustion process, flows through the Power Train with the plasma. A portion of this ash condenses as slag on the containment walls where it protects them from erosion and insulates them from the high temperature plasma. However, the ash also tends to reduce the plasma conductivity and combines with the seed, resulting in some loss of seed. Therefore, the combustor must be designed to reject a large fraction of the ash prior to the introduction of the seed.

The plasma enters the MHD channel from the combustor through a nozzle which accelerates it to the high velocity needed for power production. Its pressure, temperature and conductivity drop as it flows through the channel. MHD energy conversion stops as the conductivity approaches zero. A diffuser converts some of the kinetic energy of the MHD channel exhaust gas into an increased static discharge pressure and meets the velocity requirements of the HR/SR.

The combustion gases lose large amounts of heat to the component pressure containment walls which must be recovered to improve plant performance. This is accomplished by cooling the components with boiler feedwater.



Major system interfaces are:

- HR/SR system
- Steam power train
- Magnet system
- Coal management system
- Seed management system
- Oxidant supply system
- Electrical systems
- Slag management system

Requirements include:

<u>Parameter</u>	<u>Remarks</u>
Thermal input	532 MW
Fuel	See Section 5.0
Coal	See Section 10.0
Seed	See Section 10.0
Oxidant flow rate	See Table 4.0
Coal flow rate	See Table 4.0
Seed flow rate	See Table 4.0
Inlet pressure to combustor	See Table 4.0
Output electric power to ETF	87 MW @ 100% power level
System discharge flow rate	See Table 4.0
System discharge temperature	See Table 4.0
System discharge pressure	See Section 8.0
Electric ground	Exit of MHD Generator maintained at ground potential
Electrical isolation	All connections and supports designed to accommodate the appropriate Hall potential that varies from zero at the channel exit (grounded) to 30 kV at the combustor

### 6.1 Combustor Subsystem

The combustor will be based on designs to be tested at the CDIF. Coal combustion occurs in two stages. In the first stage, coal is gasified by partial (fuel rich) combustion with a portion of the oxidant. In the second stage, the balance of the oxidant is injected to complete the required combustion at a fuel rich stoichiometric ratio. Seed is injected into the combustor to produce the plasma required for MHD power production. The nozzle accelerates the plasma to the required velocity.

The combustor shall be designed for maximum carbon utilization, minimum pressure drop, and minimum heat loss. All wall surfaces exposed to the combustion gases are to be designed to be slag coated to reduce heat loss and to protect them from erosion. A large fraction of the ash content of the coal is continuously separated from the product gases and rejected as liquid slag. The slag removal equipment must be designed to maintain the combustor pressure

and voltage isolation from ground while adequately cooling the slag for discharge to the Slag and Ash Management System.

Major elements include:

- First stage combustor
- Second stage combustor and plasma duct
- Nozzle
- Voltage isolators for oxidant, coal and seed feed and for slag removal equipment
- Slag removal equipment

Requirements include:

<u>Parameter</u>	<u>Remarks</u>
Slag rejection	65% minimum
Stoichiometry ratio	Fuel rich, 0.9 nominal
Heat loss	5% maximum
Pressure drop	5% maximum
Cooling	High pressure boiler feedwater
Combustor turndown ratio	4:1
Materials	All metallic for rapid startup - Non-magnetic

## 6.2 MHD Generator Subsystem

The channel design is based on designs which are to be tested at CDIF. The channel is of the diagonally connected Faraday type which incorporates segmented electrode walls and barwall insulator walls. Electrodes and barwall elements are of water cooled copper and are electrically insulated from each other.

The channel design conforms to a set of limiting operational constraints that represent existing technology for channel hardware evolved from limited endurance testing.

Axial electric field	2.5 kV/m maximum
Transverse electrical field	4.0 kV/m maximum
Transverse current density	10 kA/m <sup>2</sup> maximum
Hall parameter	4 maximum

Channel electrodes are segmented to limit the voltage difference between adjacent segments to less than 45 volts. Electrode segmentation length is to be set by fabrication economics and that required to limit maximum fault power to 1 kW.



The electrode consolidation circuitry matches the raw electric power from the channel to the input requirements of the inverters. This circuitry acts to control channel loading, regulate electrode currents and stabilize channel operation. This circuitry connects the channel while maintaining the design electrode voltage and current profiles.

The Diffuser size and divergence angle are selected to attain maximum pressure recovery needed for maximum enthalpy extraction in the channel. Diffuser cooling circuits are designed for steam generation and are integrated with the steam drum of the radiant boiler.

All surfaces exposed to be combustion gases are designed to be slag coated to reduce heat loss and to protect them from erosion.

Major elements include;

- MHD channel with support structure
- Diffuser
- Consolidation circuitry

Requirements include:

<u>Parameter</u>	<u>Remarks</u>
Operational peak magnetic field	6 tesla
Channel type	Subsonic, constant mach number, Faraday barwall diagonally connected
Channel active length*	12.1 meters
Channel overall length**	16 meters
Channel heat loss	23 MW <sub>t</sub> (nominal)
Mach number	0.89 (nominal)
Channel load factor	0.68 - 0.7
Channel cooling	Low temperature boiler feedwater
Channel enthalpy extraction	20% nominal
Minimum channel operational life before refurbishing	2,000 hours
Diffuser pressure recovery factor, minimum	0.46
Diffuser cooling	High pressure boiler feedwater
Materials of construction	Non-magnetic

\*That portion of channel length lying between magnetic field values of 4 tesla at the entrance and 3.5 tesla at the exit end.

\*\*Includes inlet and outlet sections lying in the fringe magnetic fields which prevent circulating currents from being driven by the Hall potential.

### 6.3 Inverter Subsystem

The inverter subsystem converts consolidated but unfiltered, dc electrical power from the MHD generator subsystem, to fixed voltage, 3 phase, constant



frequency ac power and delivers it to the ETF switchyard. The subsystem regulates the dc electrical power input from the consolidation circuitry. It acts to control the dc input voltages and currents within the stated operational limits by varying the instantaneous rate at which power is converted and delivered to the output bus. It acts within its capacity to maintain operational conditions at the output bus within normal limits. It is designed to protect the power train from external electrical disturbances by disconnecting itself from the inverter bus whenever the normal limits are exceeded for an indefinite period of time, or whenever the bus emergency limits are exceeded. It protects the other electrical systems within the ETF from disturbances caused by the MHD power train.

Cooling is required for the inverter subsystem to maintain inverter components within the design and allowable temperature operational limits. Type of coolant and degree of cooling will be determined by the component design. In the event of inverter malfunction the inverter will shut itself down and force both the dc bus current and the ac currents into the inverter bus to zero.

Major elements include:

- DC bus input switchgear
- DC input filter and smoothing reactor
- DC interrupter
- Inverter bridges
- VAR generator
- Harmonic filter
- Output transformer
- AC switchgear
- Protective devices

Requirements include:

<u>Parameter</u>	<u>Remarks</u>
Output ac power	90 MW nominal
Voltage	34.9 kV
Output frequency	60 cycle
Power factor	0.95 leading to 0.8 lagging

#### 6.4 MHD Control Subsystem

This subsystem controls and regulates combustor operation and plasma conductivity by controlling coal, oxidant and seed input to the combustor for the required power level demand. The subsystem acts to control the MHD channel electrical load through sensing and measurement of the electrode power take-off currents and voltages, and the switching and modulation of active electrical control elements within the consolidation network. It also acts to regulate the flow of two terminal DC electrical power into the inverter and to connect or disconnect itself from the inverter as required.

This subsystem informs the supervisory control system (facility control system) of the status of the MHD power train and detects abnormal operation. It acts to stabilize the power train within its operational range through coordinated control of the combustor, generator, and electrical consolidation circuitry.

Major elements include:

- Controller card rack
- Remote/local control panel
- Controller signal cabling
- Sensors -
  - Combustor temperature transducers
  - Combustor pressure transducers
  - Combustor flame detector
  - Generator plasma conductivity RF probe
  - Consolidation circuitry voltage transducers
  - Consolidation circuitry current transducers
- Actuators -
  - Combustor coal delivery speed control actuator
  - Combustor oxidant inlet valve actuator
  - Seed inlet valve actuator

## Section 7

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## 7.0 Magnet

The superconducting magnet provides the magnetic field required by the MHD generator for power extraction. It contains a cavity (warm bore) in which the MHD generator is mounted, axis horizontal. An electrically insulated, water cooled liner, considered part of the magnet warm bore, protects the magnet from the effects of generator electrical failure and/or burn-out.

The warm bore will be accessible only from the ends. It will therefore be necessary that wiring and piping from the channel be brought out at the ends and that means be provided for withdrawing the channel and associated parts end-wise from the magnet for channel repair or replacement.

The magnet winding and associated structure must be continuously cooled by cryogenic fluids and thermally insulated. The magnet will be kept at cryogenic temperature at all times except during extended "dead plant" periods.

Significant fringe magnetic field will exist outside the magnet enclosure. The facility must be so arranged that personnel and magnetically affected equipment are kept sufficiently remote from the charged magnet, or are otherwise protected from adverse effects of magnetic field.

The magnet system is an integrated assembly of five major elements:

- Magnet assembly
- Cryogenic support equipment
- Power supply
- Protection/control circuitry
- Vacuum pumping equipment

Major interfaces are:

- MHD power train
- Magnetic interactions with personnel and equipment (forces and torques) in the vicinity of the magnet assembly

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Magnetic field	The magnet shall provide the steady magnetic field required to produce electrical power from the MHD generator whose requirements are given in Section 6.2 of this document.

<u>Parameter</u>	<u>Remarks</u>
Peak on-axis field	As required for MHD generator.
On-axis field profile	As required for MHD generator.
Transverse field uniformity	As required for MHD generator.
Cavity dimensions	The height and width of the cavity (inside the water cooled liner), its divergence and the warm bore length shall be suitable to accommodate the MHD generator described in Section 6.2 of this Document.
Channel support	The cavity warm bore and water cooled liner shall be capable of supporting the channel and other parts of the power train located within the magnet.
Charging time	The maximum time required for charging the magnet from zero current to full design field strength shall be no greater than 1 hour.
Emergency discharge	The emergency dump time constant (time to discharge the magnet from rated current) shall not exceed 3 minutes when the magnet is discharged using the (emergency) dump resistor.
Normal discharge	The maximum discharge time (time to discharge the magnet from rated current to zero current) shall be no greater than 1 hour, when the magnet is discharged under normal (non-emergency) conditions.
Scalability	The Magnet System for ETF shall be scalable to commercial scale MHD plants.

### 7.1 Magnet Assembly

The magnet assembly will provide magnetic field for the MHD channel mounted in its warm bore.



Major elements include:

- Superconducting winding (coils)
- Winding containment vessel
- Force containment structure
- Thermal radiation shield
- Low-heat-leak supports
- Vacuum vessel (magnet enclosure) including warm bore
- Water cooled warm bore liner
- Vapor cooled electrical leads
- Internal instrumentation, wiring and piping

### 7.2 Cryogenic Support Equipment

The cryogenic support equipment provides for cooling down the superconducting magnet windings, maintaining them continuously at liquid helium temperature during facility operating and standby periods and warming up the windings when an extended dead plant condition is anticipated.

The equipment will require facility supplied electrical power, cooling water and liquid nitrogen. In addition, an initial charge of helium and periodic supply of makeup helium will be required.

The major elements of cryogenic equipment include:

- Helium refrigerator/liquefier
- Helium compressor package
- Helium purifier
- Liquid helium storage vessel
- Gaseous helium storage vessel
- Cooldown heat exchanger
- Warmup heat exchanger
- LHe/LN<sub>2</sub> transfer line system
- Utility vacuum pumping system
- Instrumentation and controls

### 7.3 Power Supply

The power supply provides for charging the magnet, maintaining it at the desired field strength during MHD generator operation and discharging it under both normal and emergency (fast) shutdown conditions.

The equipment will require facility supplied electrical power and cooling water.

The major elements of the power supply include:

- Rectifier power supply unit
- Free wheeling diode unit
- Dump resistor
- Dump resistor switch
- Controls



#### 7.4 Protection/Control Circuitry

The protection/control circuitry provides protection against adverse effects of magnet system malfunction and permits remote monitoring and control of major functions of the magnet and associated equipment at the station control room.

The major elements of protection/control circuitry are:

- Magnet quench detection system
- Magnet liquid helium level monitoring system
- Vacuum monitoring system
- Vapor cooled power lead temperature monitoring system
- Automatic warning/emergency shutdown system responsive to critical monitored parameters
- Remote magnet charge/discharge controls

#### 7.5 Vacuum Pumping Equipment

The vacuum pumping equipment provides for evacuating the magnet vacuum jacket prior to and during initial magnet cooldown. When cooldown has progressed sufficiently to provide significant cryopumping, the vacuum pumping equipment will be valved off and cryopumping will maintain vacuum during magnet operation and cold standby.

(Note: This Section covers the vacuum pumping equipment for the magnet vacuum jacket only. Utility vacuum pumping equipment for cryogenic support equipment is covered in Section 7.2).

The major elements include:

- Vacuum valve at vacuum jacket pumpout connection
- Diffusion pump or equivalent
- Liquid nitrogen cooled trap
- Mechanical (fore) pump
- Vacuum gages

## Section 8

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## 8.0 Heat Recovery and Seed Recovery (HR/SR)

The HR/SR System processes the exhaust gas from the MHD Power Train in order to improve the overall plant performance by recovering the residual available energy, to recover potassium seed for possible reuse, and to meet EPA effluent requirements. The system is comprised of two major subsystems, comparable to the boiler and the particulate control system in a conventional fossil-fueled powerplant, but having added or modified features to accommodate the MHD process. The HR/SR functions are:

- Produce superheated and reheated steam for power generation
- Preheat the MHD oxidant
- Recover seed material ( $K_2SO_4$ ) in a form suitable for reprocessing
- Reduce  $SO_x$  &  $NO_x$  inventory Below the EPA emission standards
- Complete combustion of the combustibles in the flue gas inventory in order to produce additional usable heat and to reduce the CO and hydrocarbon content to below EPA emission standards, and to provide sufficient oxygen partial pressure to assure a high percentage of  $K_2SO_4$  formation.

The major elements of the system are:

- Boiler (including MHD oxidant heater)
- Particulate control subsystem

Major interfaces include:

- MHD power train
- Oxidant supply
- Coal management
- Steam power train
- Flue gas discharge
- Seed management
- Slag/ash management

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Incoming gas conditions	See Table 4.0
Exiting gas conditions	See Table 4.0, Exit temperature of (480°F) is required for coal drying



<u>Parameter</u>	<u>Remarks</u>
Exiting gas conditions (maximum permissible)	
Particulates	0.03 lb per million Btu input and 1% of potential combustion concentration and 20% opacity (6 minute average) plus 27% opacity (one minute period per hour)
Sulfur Dioxide	1.20 lb per million Btu input and 10% of potential combustion concentration.
Nitrogen Oxide	0.50 lb per million Btu input and 35% of potential combustion concentration.
Unburned hydrocarbons	TBD
Carbon monoxide	TBD
Seed recovery	
Flow	See Table 4.0
Reusable fraction	TBD
Oxidant heating capacity	
Temperature	432°F in and 1100°F out
Flow & pressure	See Table 4.0
Steam Conditions	
Superheat pressure, psia	1,910
Superheat temperature, °F	1,005
Reheat pressure, psia	See Table 4.0
Reheat temperature, °F	1,001
Flows	See Table 4.0

### 8.1 Boiler

The boiler performs all of the functions of the HR/SR System in total excepting seed recovery and particulate control which are shared with the Particulate Control Subsystem. The boiler components contain the exhaust gas and transfer heat to the steam supply for the turbines and the MHD oxidant. The components must be configured and integrated so that the exhaust gas processing functions are accomplished.

The major components of the Boiler are:

- NO<sub>x</sub> control furnace (lower radiant boiler)
- Afterburner (upper radiant boiler and air windbox)
- Convection pass enclosure
- Steam drum, recirculating pumps and piping
- Superheater and attemperator
- Reheater and attemperator
- Intermediate temperature oxidant heater (ITOH)
- High temperature economizer
- Soot blowers

A typical steam drum configuration is used for separating the steam from the recirculating water, but special considerations must be made in the design of the recirculating water system to ensure adequate cooling of the diffuser and transition section. Steam heating in the superheater and reheater is conventional, but the design of these components must take into account corrosion and fouling problems caused by the heavy seed loading of the flue gas. Spray attemperators are used to control and maintain steam superheat and reheat exit temperature at part load.

The Intermediate Temperature Oxidant Heater preheats oxidant from the Oxidant Supply System to 1100°F for use in the MHD combustor. The preheat temperature is limited by material and corrosion considerations.

In order for the boiler to control plant emissions and recover the seed it must provide the proper conditions for the completion of a variety of chemical reactions during the cooling of the flue gas. Oxides of nitrogen (NO<sub>x</sub>) will be reduced in the boiler by designing the NO<sub>x</sub>-Control Furnace, the entrance section of the Radiant Boiler, to control the cooling rate of the flue gas. The equilibrium NO<sub>x</sub> value is approached prior to the time when the gas reaches the temperature (approximately 2900°F) where the reduction reactions are frozen.

The completion of combustion of the exhaust gas to eliminate unburned hydrocarbons and carbon monoxide is accomplished in the upper portion of the radiant boiler (afterburner) using preheated air from the Afterburner Gas Supply System. The afterburner must be designed to obtain complete combustion and yet avoid temperatures which would reform NO<sub>x</sub>. The design must avoid local zones having a reducing atmosphere which would cause corrosion of the superheater and other heat exchange surfaces.

The boiler participates in the recovery of the seed from the flue gas because both seed and slag condense and collect on the heat transfer surfaces. Since it is uneconomical to recover seed that has dissolved in slag, it is necessary to design the boiler to physically separate the collection zones for the two substances. The NO<sub>x</sub>-Control Furnace shall have slagging walls. The secondary superheater shall collect wet seed while the other convective surfaces shall collect dry seed. Soot blowers are provided to remove the seed from the surfaces so that it falls into



the hopper at the bottom of the convection pass. Subsystem requirements include:

<u>Parameter</u>	<u>Remarks</u>
Boiler type	Balanced draft Controlled recirculation
NO <sub>x</sub> -Control Furnace	
Inlet NO <sub>x</sub> content	approx. 1500 ppm
Exit temperature	2900°F
Residence time	2.2 seconds (min)
Afterburner	
Final stoichiometry	1.05
Convection pass	
Attemperation control point	80% steam flow
Gas temperature at secondary superheater	2400°F

## 8.2 Particulate Control Subsystem

This subsystem reduces the inventory of all particulates in the plant gas effluent to below the environmental standards and completes the recovery of the seed from the flue gas. It does not include the clean up of the coal drying medium which is performed by the Coal Management System. The subsystem is comparable to the one in a conventional pulverized coal fired power plant, but it must contend with a much higher loading of very fine particulates. Major elements include:

Electrostatic precipitator  
 Duct work  
 Instrumentation and control

It is anticipated that the greatest portion of the particulates will be spent seed in the form of  $K_2SO_4$ . The particulate control subsystem will operate at a slightly sub atmospheric pressure and 480°F temperature.



## Section 9

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## 9.0 Steam Power Train

The Steam Power Train consists of those systems necessary to generate electricity from steam produced in the HR/SR System. The major elements are:

- Main steam turbine and auxiliaries
- Generator and field excitation
- Steam piping and valves
- Condensate
- Boiler feedwater
- Water treatment
- Circulating water system
- Steam power train facilities

Major interfaces include:

- HR/SR
- Electrical system
- Oxidant supply system
- MHD power train

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Superheat steam flow from HR/SR	See Section 4, Table 4.1
Superheat pressure at outlet	1,910 psia
Superheat temperature at outlet	1005°F
Reheat steam flow from HR/SR	See Section 4, Table 4.1
Reheat temperature at outlet	1001°F
Generator output	128 MW (Reference)
Steam to compressor and boiler feed pump drive turbines	310,553 lb/hr
Waste heat rejection	Atmospheric

## 9.1 Main Steam Turbine and Auxiliaries

The main turbine provides the shaft power to drive the alternating current generator.

Major elements include:

- High pressure casing containing the high pressure turbine and reheat turbine sections
- Low pressure casing containing a double flow (balanced) low pressure turbine
- Speed governing
- Steam sealing
- Lubrication
- Safety and protection
- Insulation and lagging

Requirements include:

Unit shall be for utility service.  
Size selection shall be from standard available equipment.  
Operating parameters shall be consistent with the plant cycle diagram.

9.2 Generator

The turbine generator set supplies electrical power to the utility grid and supplies power for plant auxiliaries. Isolated busses for each electrical phase transfers generated ac power through a step-up transformer to the switchyard.

Requirements include:

Guaranteed generator MVA rating (at specified power factor and hydrogen pressure) shall correspond to the maximum expected megawatt output of the turbine at maximum conditions with valves wide open, specified steam temperature, and specified condenser vacuum.

The generator rotor and stator shall be hydrogen cooled.

The operating voltage and the number of generator bushings will be recommended by the turbine-generator manufacturer.

The rotor short term capability for operation with unbalanced stator fault currents shall be in accordance with the latest version of ANSI Standard C.50.13.

Current transformers conforming to appropriate ANSI standards shall be installed in the line bushings and neutral bushings for metering, relaying, and voltage regulation.

The generator stator winding shall be grounded. Field excitation shall be static type. Lubrication and excitation auxiliaries shall be conventional.

The rated voltage of the isolated phase bus duct shall be satisfactory for the generator maximum design operating voltage.

The isolated phase bus between the generator and main step-up transformer shall be rated to continuously carry rated generator MVA at 95% of rated generator voltage, within standard temperature limits.

Manufacturer will recommend exact cooling requirements.

Self-cooled taps to auxiliary transformers shall be rated to carry the transformer maximum forced-cooled MVA rating at 95% rated generator voltage.



Rated momentary current shall be based on the maximum three phase fault current to which the bus can be subjected.

The bus duct and accessories shall be designed, constructed, rated, tested, and shall perform in accordance with the applicable portions of ANSI Standard C37.20.

Disconnect links shall be provided to enable safe maintenance of the generator.

### 9.3 Steam Piping and Valves

#### 9.3.1 Main Steam

The main steam piping transports steam from the superheater to the high pressure turbine.

Requirements include:

Rating of main steam piping from the HR/SR shall be determined to meet main throttle conditions.

The main steam system shall be all welded construction in accordance with the ASME Boiler and Pressure Vessel Code, Section I. (Chrome-moly steel material shall be used for the main steam piping subject to verification by design study). Code certification shall be required.

The design pressures, temperatures, and flow rates shall be those occurring at turbine valves wide open conditions. The main steam piping system shall be designed to include anticipated pressure drop at maximum load while limiting steam velocity to a value which will not cause damage to the piping.

#### 9.3.2 Reheat Piping

The reheat piping transports steam to and from the reheater in the HR/SR.

Requirements include:

The reheat steam system shall be all welded construction in accordance with ANSI B31.1. Hot reheat piping shall be chrome-moly steel. Cold reheat piping shall be carbon steel.

To assure proper reheat turbine operation, initial design of reheat piping shall allow for a preset pressure drop in the reheat system, properly balanced among cold reheat piping, reheater and hot reheat piping.

### 9.3.3 Low Pressure Piping

(TBD)

### 9.4 Condensate

The condensate system condenses and deaerates turbine exhaust steam and pumps condensate through the demineralizer to the deaerator and storage tank. In addition, the system will provide cooling for a steam jet air ejector, the seal steam condenser, and a water supply for water requirements in the plant, such as turbine exhaust sprays and pump seal injection.

Major elements include:

Condenser

Vacuum exhauster

Condensate pumps

Demineralizer

Deaerator and deaerator storage tank sized to hold enough water to protect the system from damage during rapid load changes.

A large storage tank to provide condensate for cycle makeup.

The requirements include:

The condensate system piping shall be welded carbon steel construction in accordance with ANSI B31.1.

The deaerator and deaerator storage tank shall be in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

The condenser shall be a single pressure surface unit utilizing standard materials of construction suitable for cooling tower quality water.

The condenser shall be designed in accordance with ASME Boiler and Pressure Vessel Code Section VIII and the standards of the Heat Exchange Institute. Noncondensables extraction from the condensate within the condenser shall be by a vacuum exhaust system.

Condensate storage shall be provided on the site with a condensate capacity sufficient to fill the system and make up minor losses during unit operation.

The condensate storage tank shall be designed in accordance with AWWA D.5.2-73 of the American Water Works Association.



### 9.5 Boiler Feedwater

The boiler feedwater system takes condensate from deaerator storage, preheats and delivers the water to the HR/SR to meet the design steam generation conditions. Boiler feed booster pumps raise the condensate pressure sufficiently to pass it through the MHD Channel cooling circuit, a low temperature economizer, and provide adequate suction head for the main boiler feedwater pumps. The main pumps then provide additional system pressure to pump the water through regenerative feedwater heaters, a high temperature economizer (in the HR/SR), MHD combustor and nozzle cooling circuits, and into the HR/SR steam drum.

The main elements include:

- Boiler feed booster pumps
- Boiler feed pumps
- Regenerative feedwater heaters
- High and low temperature economizers
- MHD power train cooling circuits

Requirements include:

The boiler feed pumps will provide sufficient discharge pressure to meet the pressure requirements to the steam drum.

Boiler feed booster pumps will provide sufficient discharge pressure to prevent vaporization of the feedwater.

Boiler feed piping shall be welded carbon steel in accordance with ANSI B31.1 and the ASME Boiler and Pressure Vessel Code. Code certification shall be required.

Regenerative feedwater heaters will be used to improve cycle efficiency by heating feedwater to the HR/SR using extraction steam from the high and intermediate temperature turbines.

High pressure feedwater heaters shall be designed to Section VIII, Division I, of ASME Pressure Vessel Code, and the Heat Exchange Institute (HEI) Standards for Closed Feedwater Heaters, latest edition.

Economizer (Refer to HR/SR Section 8.0, and Flue Gas Discharge Section 10.5) capability to provide minimum continuous cooling to MHD power train components.

Capability to provide minimum continuous cooling to MHD power train components.

### 9.6 Water Treatment

Refer to Sections 9.4 and 11.2.



### 9.7 Circulating Water System

A closed circuit cooling system cools exhaust steam from the main turbine and the boiler feed pump turbine and provides cooling for various plant equipment. The ETF design will be based on evaporative mechanically induced draft cooling towers.

Major components include:

- Cooling towers
- Circulating water pump
- Service water pumps
- Plant heat exchangers

Requirements include:

Water temperature shall be sufficiently cool under the worst atmospheric conditions to maintain condenser vacuum at or below the maximum absolute pressure required by the turbine.

Circulating water shall not reach temperatures which would cause the secondary plant cooling loop to exceed the maximum allowable coolant temperature for any component in that loop.

The tower orientation and location shall be such that the plume created by evaporation will not impinge on or obscure nearby facilities nor be ingested by plant compressors.

Water shall be discharged (blowdown) from the loop and make up added to avoid a buildup of solids.

Blowdown flows shall meet regulatory requirements for temperature and solids concentration limitations.

Chemical treatment shall be utilized to control biological growth in the recirculating water.

Circulating pumps shall be sized to take water from the basin of the cooling tower and deliver it through the condenser and back over the tower.

Service water pumps shall be sized to pump water from the cooling tower basin and deliver it through plant heat exchangers and back over the tower.

Protection against cooling tower freezing.

The cooling tower is sized for the following design conditions are:

Wet bulb temperature	59°F
Water outlet temperature from the cooling tower	69°F
Water inlet temperature at the cooling tower	92°F
Temperature of condensate from main condenser	101°F

The design wet bulb temperature is not exceeded more than 2-1/2 percent of the year.

#### 9.8 Steam Power Train Facilities

The turbine-generator building shall enclose the steam turbine-generator and its related auxiliary equipment. The building shall be structural steel frame type construction and shall be divided into bays.

Requirements include:

The structures shall be designed to meet the Uniform Building Code and ANSI A58.1 Building Code Requirements for minimum design loads in buildings and other structures.

A traveling bridge crane shall be provided.

#### 9.9 Auxiliary Steam System

The Auxiliary Steam System will provide low pressure steam from packaged boiler units. This system will provide steam for plant heating and for auxiliary services during startup and during cold weather plant operation. The steam generated will be passed to a header system and throttled to provide steam at two different pressure levels to meet the plant requirements.

Major elements include:

Package boiler units  
Steam piping and valving

Major system interfaces for primary steam include:

Startup air preheater  
Auxiliary deaerator  
Steam coil air heaters  
Auxiliary sparger  
Main steam turbine

For secondary steam include:

Building heaters  
Flue gas sampler  
Condensate demineralizer  
Main steam turbine

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Primary steam pressure	TBD
Primary steam temperature	TBD
Secondary steam pressure	TBD
Steam flow rate per boiler	TBD



## Section 10

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## 10.0 Plant Auxiliary Systems

This section describes those systems which are in direct support of overall power generation in the ETF. These include:

- Coal management
- Flue gas discharge
- Slag (ash) management and disposal
- Seed management
- Plant electrical
- Plant control complex

### 10.1 Coal Management

This system provides dried, pulverized, and metered coal to the MHD Power Train. The coal will be dried to 5% moisture or less. Gas for coal drying will be either hot flue gas or nitrogen gas from the Air Separation Unit. The actual source and conditioning for its use is dependent upon engineering analyses results yet to be obtained. Coal will be delivered to the combustor via a system operating at approximately 4.5 atmospheres.

Coal will arrive by rail. The coal handling system conveys coal from the delivery point to the stockpile and also directly to the plant bunkers. Coal will be weighed and sampled as received and as fired. Crushers will be available for oversized coal, and for frozen coal. Backup facilities will be provided from the stockpile into the plant to ensure availability of coal at the bunkers. Coal car thawing sheds will also be provided to facilitate winter unloading of the coal unit trains.

Sized coal from storage will be weighed and fed from the bunkers to pulverizers. Hot gas will be blown through the pulverizer to act as the transport medium for the pulverized coal and to remove moisture in the coal. The pulverized coal will be separated and collected from the gas conveying stream by a baghouse. Collected coal will first be transported to the small intermediate bunkers, filled with an inert gas to prevent spontaneous combustion, and sent to the pressurized lockhoppers.

The functions of the ETF Coal System are:

- Process the "as delivered" coal into the desired size and dryness.

- Transport and store the processed coal in a manner that will prevent the prepared coal from burning, clumping or undergoing other changes of state that would reduce the heating value or prevent uniform and dependable feeding of the coal to the combustor.

- Feed coal into the MHD combustor.

Major elements of this system include:

- Thawing sheds
- Car unloading mechanism
- Stockout mechanism
- Crushers
- Conveying system
- Pulverizers/dryers
- In-plant bunkers
- Scalping screen
- Lock hopper systems

Major system interfaces include:

- MHD power train
- Plant rail system
- HR/SR
- Flue gas discharge system

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Fuel	Coal, Montana Rosebud, run of mine
Moisture, as delivered	22.7%
Moisture, after drying	5% maximum
Final sizing	70% passing a 200 mesh screen
Flow rate	See Section 4, Table 4.0
Active storage	Min. of 72 hours at max. burn rate
Inactive storage	Two 30-day piles
In-plant storage	One shift per day operation
Delivery belts	One shift per day operation

## 10.2 Seed Management

This system supplies dry pulverized seed to the MHD Power Train, and recovers used seed. The seed is supplied as a mixture of potassium sulfate ( $K_2SO_4$ ) with an amount of potassium carbonate ( $K_2CO_3$ ) adequate to capture the sulfur in the coal. The Seed Management System: (1) receives and unloads fresh seed from off site; (2) recovers used seed ( $K_2SO_4$ ) from the boiler and ESP; (3) transports, stores, pulverizes and mixes prescribed fractions of fresh seed ( $K_2CO_3$ ) and recycled seed (or fresh  $K_2SO_4$  from off site); (4) injects mixed seed into the MHD combustor at a controlled rate; (5) and transports used seed off site for disposal or reprocessing.



Major elements of seed management are:

Seed feed  
 Seed recovery  
 Seed handling and storage

Major interfaces are:

MHD power train  
 HR/SR system  
 Flue gas discharge system  
 Slag management  
 Plant rail system

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Seed	Potassium in the form of a $K_2CO_3$ - $K_2SO_4$ mixture
Feed rate	1.0% potassium by weight in the total gas flow
Physical form	Solid
Mixture ratio	39% $K_2CO_3$ /61% $K_2SO_4$ by weight
Supply	Material from reprocessing system or commercial sources.
Particle size	TBD
Dryness	TBD
Seed recovery	Must recover minimum of TBD of the seed for recycling
Seed storage	Minimum of 72 hours at maximum coal burn

### 10.3 Slag Management

This system accepts slag and ash at discharge points in the gas flow path and the seed management system and transports it to the storage area for off-site disposal.

Major elements are:

Radiant boiler slag separator	Ash conveying system
Slag conveying system	Ash storage silos
Slag collection pond	

Major interfaces are:

MHD power train	HR/SR
Seed management	Off-site disposal system

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Slag flow rate through power train	70 ± 5% removed at combustor
Slag/ash flow rate through HR/SR	Slag removed at radiant boiler 2,173 lb/hr. Ash removal from remainder HR/SR TBD lb/hr.
Ash flow rate into flue gas cleanup equipment	Ash design loading into electrostatic precipitation 25,264 lb/hr
Disposal rate	20,300 lb/hr
Site ash storage capacity	TBD tons

#### 10.4 Afterburner Gas Supply

This system supplies ambient air to the HR/SR so that the final ratio of oxygen to fuel will be at least 1.05 stoichiometric. HR/SR temperature control will be achieved by mixing this air with recycle flue gas to limit entry temperature into the superheater. The air heater will have the capacity to preheat low temperature winter air prior to injection into the afterburner system to control corrosion.

Major elements of this system include:

- Afterburner fan(s)
- Heater(s)
- Interconnecting ducting
- Controls

Major interfaces are: HR/SR, flue gas discharge system and ambient air supply

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Ambient air supply	
Quantity	205,286 lb/hr
Delivery temperature and pressure	331°F @ 12.9 psia
Flue gas recycle	
Quantity	105,671 lb/hr
Delivery temperature and pressure	486°F @ 12.9 psia

### 10.5 Flue Gas Discharge

The flue gas discharge system transports the cleaned flue gas from the HR/SR to the low temperature economizer and to other plant uses as defined by Figure 4.0. The low temperature economizer discharge and the other subsystem clean exhaust gas streams are then collected and passed to induced draft fans for release to the atmosphere through the main stack.

The system consists of the following:

- Induced draft fans
- Stack
- Ductwork
- Instrumentation and controls
- Low temperature economizer

Major interfaces are:

- HR/SR
- The atmosphere
- Coal drying system

System requirements include:

<u>Parameter</u>	<u>Remarks</u>
Incoming gas conditions	See Section 4, Table 4.0
Exiting gas emissions	See Section 8.0
Temperature to atmosphere	230°F (nominal)

### 10.6 Electrical

The electrical systems deliver generated power from the ETF to the grid, distribute power for plant services, and provide uninterruptible power for computers and other electronic needs. (Refer to Section 3.0 for overall plant regulation requirements).

Power generated by MHD and steam turbine generators are synchronized with the Utility grid at the ETF switchyard. (Refer to Subsection 9.2.)

All generated power is transmitted to the ETF switchyard (at typically a 138 kV voltage) through generation step up transformers. The ETF switchyard connects to the Utility lines, providing a path for generated power to flow to the Utility grid and for required station auxiliary power to flow from the grid.



Major elements of the system include:

Power transformers and major elements of the ETF electrical systems and are classified as follows:

Inverter and Generator Step-Up Transformers - These units connect the MHD and steam power generators to the ETF transmission switchyard and enable the generated power to be fed into the off-site system at the transmission voltage.

MHD and TG Station Service Transformers - These step down transformers take power from the ETF switchyard and deliver it to three medium voltage 4.16 kV busses for ETF operation during startup, normal operation and shutdown.

Load Center Transformers - These transformers, fed from the plant medium voltage bus bars, provide a source of power at 480 volts for the smaller electrical loads.

The plant electrical distribution system, provides a reliable source of power for plant processes which include motive power, controls, instrumentation, communication, lighting, heating, and ventilation. This distribution is provided by three major medium voltage metal clad switchgear lineups; one associated with the turbine-generator auxiliaries, one with the MHD channel support equipment, and the third with all critical plant loads required to provide an orderly emergency plant shutdown. Bus ties provide each bus to be fed either from the MHD or TG station service transformer. This dual tie ensures station power during plant downtime.

Emergency power shall be provided to the critical 4.16 kV bus, when normal power is lost. A 125 V dc 60 cell battery and charger system provides power for emergency lighting and control and status power for all 4.16 kV and 480 V breakers along with TG turning gear and emergency bearing oil motors.

Two Uninterruptible Power Supply (UPS) 120/208 volt, 3 phase, 4 wire systems each consisting of 125 V dc batteries, redundant chargers and inverters, static automatic and manual maintenance bypass switches with voltage regulated bypass transformers provide vital instrument and control power. Vital loads consist of computers, electronic control and instrumentation equipment.

#### 10.7 Control Complex

The control system regulates the plant processes, allows the operator to exercise control over the plant, informs the operators of conditions within the plant, and performs a protection function from potential hazards for the plant and the operators. Its components include sensors which measure the process variables, the actuation mechanisms which cause changes in the control variables, and the data transmission, signal

processing and intelligence which conveys system information throughout the plant, commands the actuators to respond, and provides interfaces with the human operators. It is the total amalgamation of information gathering and communication, signal processing and memory, and the automatic decision making, regulation, switching and modulation which are required to accomplish the control system functions.

The control system performs the following functions:

Regulates plant processes and keeps plant parameters at their intended values for designed output power levels and operational modes.

Contributes to stable plant operation by initiating corrective action to unintentional disturbances by correcting the cause of the disturbance, thus minimizing the effects upon other processes within the plant.

Changes the plant output power level promptly upon command to do so, with minimum fluctuation.

Provides safe, orderly starting and stopping of plant equipment.

Controls the plant to maintain the specified load regulation and response.

Provides for plant operability under the various desired operational modes, and provides control of the plant under these modes.

Changes the plant operating mode to another mode either automatically or upon command.

Informs the operators of conditions within the plant, and displays this information in a timely and comprehensible manner.

Contributes to the protection of the plant equipment and personnel by monitoring all plant processes and conditions within the plant; thereby providing the operators timely warning of impending faults, off-design or unsafe conditions, and other potential hazards, and by initiating preplanned corrective actions, countermeasures and alarms whenever these conditions occur.

Protects the plant by acting to keep the system parameters within safe limits under all conditions, including faults and/or failures, and shutting down those portions of the plant affected by failure or damage in a safe, orderly fashion.



The major control system elements include:

- Supervisory control system
- Safety and interlock system
- Operator interface station
- Controls associated with the MHD power train
- Controls associated with the heat and seed recovery system
- Controls associated with the steam power train
- Controls associated with the electrical distribution system
- Controls associated with electrical power generation which includes the MHD power train, inverter and rotating electrical machinery
- Controls associated with coal, oxidant, and seed feed

The control system interfaces with all of the plant systems within its purview, and has major control interfaces with the following:

- The plant operators
- The utility load dispatch
- Controls associated with the air separation unit
- Controls associated with the channel magnet system
- Controls associated with other plant operating auxiliaries.

The control system also interfaces with all users of facility data not specifically related to control system functions.

Control system requirements include:

Design to incorporate the most reasonable and practical level of automation; that is, to maximize those desired plant characteristics such as system response, economy, reliability and safety while keeping the scope of required procedures within a reasonable comprehension area for human operator participation.

Capability of being alterable with respect to its information gathering, processing and display characteristics without any hardware modifications whatsoever. THIS DOES NOT APPLY TO SAFETY AND INTERLOCK SYSTEM.

Design to provide fully automatic operation under Baseload, Standby, and Emergency Shutdown operational modes. Semi-automatic/manual operation is allowed under all other operational modes.

Hardwired safety and interlock systems which have supervisory authority, take their information directly from control system sensors and not other control systems, and separately contain the levels of information processing and decision making capability necessary to generate alarms and execute override commands. They do not in themselves contain all of the safety related functions used to monitor the plant but only those critical safety functions required to prevent major damage, serious injury, or loss of life.

Applicable Codes and Standards

TBD



## Section 11

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## 11.0 Plant Services

This section outlines the basic requirements for many peripheral plant services, systems, and facilities not directly in the power generation trains but which provide the ancillary needs of the facility.

### 11.1 Compressed Air

Compressed air is provided for plant service and instrument use.

Plant air shall be provided at nominal 125 psig. Instrument air, dry, and free of oil, shall be provided at 100 psig.

### 11.2 Water

This system provides water for cycle makeup, fire protection, potable use, sanitary service, and other plant needs.

Water treatment requirements for cooling tower (C.T.) and ash handling use include:

- Chlorination
- Retardation of biological plant growth (C.T. only)
- Corrosion protection (C.T. only)

Demineralized high purity water provides water makeup to closed cooling systems and water for instrument and laboratory use. This demineralizer shall be a mixed bed unit with a capacity equal to approximately 3 percent of the main steam mass flow. Water treatment requirements for demineralized closed cycle cooling makeup, potable, sanitary, seed recovery and fire service use include:

- Chlorination
- Clarification
- Filtration
- Demineralization

### 11.3 Lighting

Lighting throughout the plant consists of two separate types of systems:

Normal lighting, whose function is to provide illumination during normal operation conditions.

Emergency lighting, for purposes of personnel egress and continuation of critical activities during emergency conditions.

Requirements include: light systems shall be installed according to the National Electric Code supplemented with Underwriters Laboratory listings. Illumination levels shall be TBD.

#### 11.4 Communication

(TBD)

#### 11.5 Fire Protection

Plant fire protection consists of systems designed to combat specific hazards. Fire protection systems throughout the plant will meet NFPA standards.

#### 11.6 Security

Security techniques include capability to resist willful attempts to damage or remove property. The main function of the security system is to provide controlled access to the site.

Entrance to the plant shall be through a manned, monitored guard house. An outer fence protects the site area, and inner fences provide controlled access to plant vital areas.

#### 11.7 Plant Service Building

The Plant Service Building houses administrative offices, medical dispensary, records and study rooms, training rooms, auditorium, storage rooms, toilets and showers, lockers, kitchen, lunch room, machine and tool shops, and laboratories. Space and equipment for each area shall be commensurate with plant needs.

#### 11.8 Maintenance

The MHD power train will require establishment of maintenance procedures which are commensurate with the unique equipment and its exposure to temperature extremes in conjunction with erosive atmospheres. Typical maintenance procedures are well established for the botloming plant. Adequate maintenance procedures shall be prepared for all systems to conduct maintenance on a planned schedule.

#### 11.9 Logistics

The facility shall provide for a programmed supply of coal, seed, fuel oil, water, chemicals, lubricating oils and greases, industrial gases, maintenance and housekeeping material. Provisions shall also include transportation, installation, and storage for unusually large or heavy components unique to this facility.



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